Pixel Summary IF

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Physics areas: The application and ubiquity of noble liquid time projection chambers (TPC) in the fields of high energy physics, medical imaging, and rare event searches is due to the many attractive properties noble elements provide. As charged particles traverse the bulk material they produce ionization electrons and scintillation photons. An external electric field allows the ionization electrons to drift towards the anode of the detector and be collected on charge sensitive readout. The combined measurement of the scintillation light, providing a start time for the event t_0, and the arrival time of the ionization charge allows for the 3D reconstruction of the original charged particle topology within TPC. Recently, the advances in large scale liquid noble TPC's to drift electrons over many meters has lead to a rise in their use as neutrino detectors to study of neutrino oscillations, neutrino-nuclei interactions, and their application for rare event searches (such as dark matter and neutrinoless double beta decay).

The standard method for reading out the ionization charge in a noble element TPC relies on the use of consecutive planes of sensing wires to measure two of the three space coordinates. Although the concept is proven and gained considerable interest in the community [1–3], it has an intrinsic limitation in resolving ambiguities, resulting in potential failures of the event reconstruction. In addition, the construction and mounting of massive anode plane assemblies to host thousands of finely spaced wires poses difficult engineering challenges and is considerably expensive. For these reasons, a non-projective readout present many advantages. Such a non-projective readout scheme has been utilized in many gas based TPC, but the large number of readout channels and power consumption requirements have posed significant challenges for applicability in liquid noble TPC. The number of pixels for equal spatial resolution will be two or three orders of magnitude higher than the number of corresponding sense wires, with an analogous increase of the number of signal channels, data rates and power dissipation. A transformative step forward for future liquid noble TPCs is the ability to build a fully pixelated low power charge readout. The endeavour to build a low power pixel based charge readout for use in LArTPC's has independently inspired the LArPix [4] and Q-Pix [5] consortium to pursue complimentary approaches to solving this problem.

The benefits of a native 3D readout for noble element TPC's is evident. The increase in signal fidelity through the removal of 2D to 3D projective readout, the subsequent increases in reconstruction efficiency and purity, and the ability to accurately reconstruct final state topologies with greater detail have been observed [6]. Exploration into the various pixel architectures has also begun to show enhancement in the capabilities to reconstruct low-energy events ($\mathcal{O}(\leq 5)$ MeV) with improvements in overall data rates and signal fidelity [7]. Additional work is ongoing to fully explore the physics potential realized by a pixel based noble element readout, but initial studies are promising.

Instrumentation Requirements:

As noted above, the application of pixels into noble element TPC's comes with an wide array of performance requirements. These requirements are broadly classified in terms of the readouts noise, power, and reliability in a cryogenic environment. While the specifics are defined by their bespoke application, the general themes of power requirements < 10 W/m^2 average power with mm scale pixels, ≤ 500 e^- equivalent noise charge (ENC), sub-% failure tolerance across a system with millions to billions of channels.

Along with the requirements on the pixel readout electronics themselves comes requirements on system reliability and scalability. A robust input/output (I/O) architectures is needed to faithfully bring the data from the large number of channels created by a pixel readout to a central data logger. While this challenge is not unique to pixel readouts per se, there is a demand on the readout architecture to not introduce any noise as the threshold for sensitivity of the pixels aims for lower and lower targets. To scale these devices to large experiments, groups must leverage commercial methods for mass production. This includes targeting ASIC and printed circuit board (PCB) manufacturing processes that are well suited for low-cost and high reliability to allow for the production of the pixel readout anode on a large scale.

In order to detect scintillation light, the chamber is equipped with a light collection system sensitive to VUV light (128-178 nm) to be integrated with the pixel plane.

Instrumentation challenges:

As the pixel technology continues to mature, there is a drive to push the detection threshold limit as low as possible. Future experiments want to be ready for discovery while maintaining the fidelity of high energy depositions. Such lower thresholds could allow for the application of pixel based noble element TPCs to explore beyond the standard model physics as well as probe into areas of low threshold detection (e.g. dark matter and neutrinoless double beta decay) which have been focused only on the light created in the TPC. As the thresholds are lowered, this introduces a challenge for the circuits "dynamic range" as well as ensuring that data rates stay manageable. This will require new readout designs and architectures to be proven in both gas and liquid noble detectors.

The need for finding and sharing common solutions within the community of researchers pursuing pixel based readout for noble element TPCs is a key instrumentation challenge. Often arbitrary barriers due to various intellectual property concerns of the ASIC foundries cause multi-institutional collaboration to be difficult if not impossible. This slows the progress of R&D. Platforms such as the CERN R&D collaboration have found ways to overcome this and has been essential for delivering technologies used by the current generation of large high-energy physics experiments. The creation of a similar platform within the US would allow for the best ideas to come together into a final viable design with efficient use of available resources. This structure would greatly enhance the cooperative technology development across multiple experiments

Another key instrumentation challenge is the integration of photon detection into a pixel readout. The pixel anode planes offer an opaque and heavily occupied space, in contrast to the semi-transparent wire based projective readout. Thus efforts into new technologies for light readout are needed to maintain the ability to reconstruct the signal with the best energy and timing resolution. An exciting area of R&D attempting to address this is the development of a multi-modal pixel technology which can read out simultaneously ionization charge and VUV light from the TPC. Such a sensor could integrate charge (Q) and light (L) signals into a single readout sensor and (with the proper choice of photoconductive material) have a broad frequency response capable of detecting the full spectrum of light produced in noble element TPC. Ongoing work into a number of candidate materials and geometries (including amorphous selenium, organic semiconductor devices, pyroelectric Zinc Oxides, and more) is underway and may provide transformational step forward for noble element based detectors. Such a new detector element would offer: i) the intrinsic fine grain information for both the charge and light opening up new exciting possibilities to exploit the imaging capabilities for both signals, ii) monumentally enhance the amount of light collected through increased surface area coverage, and iii) simplification in the design and operation of noble element detectors.

References

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